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# PRINCIPLES OF MATHEMATICAL MODELING THE CONSENSUS ACHIEVEMENT DURING THE DEVELOPMENT OF REGULATORY DOCUMENTS REQUIREMENTS FOR METAL PRODUCTS

***Abstract:*** *Consensus is the main principle defining the process of standardization. At present time there are no any criteria which can be used for the assessment the consensus achievement. In this paper it was proposed to use the mathematical model of S-curve diagram in order to define the level of consensus achievement during the development the regulatory documents requirements for metal products. Mathematical model is based on the peculiarities of setting metal ware quality indices in normative and technical documentation. The examples of carbon steel wire and hexagonal screw mechanical properties regulation were chosen in order to prove the accuracy of the developed mathematical models. The proposed approach can be used for quantitative assessment the consensus achievement during setting norms in different regulatory documents for metal products.*

***Keywords:*** *consensus, S-curve, regulatory document, metal product*

## 1. Introduction

One of the basic principles of quality management is orientation to customer demands. In the international standard ISO 9001-2015 the necessity of implementation the quality management system is ground in the following way: «An organization focused on quality promotes a culture that results in the behaviour, attitudes, activities and processes that deliver value through fulfilling the needs and expectations of customers and other relevant parties. The quality of an organization's products and services is determined by the ability to satisfy customers and the intended and unintended impact on relevant interested parties. The quality of products and services includes not only their intended function and performance, but also their perceived value and benefit to the customer». Hence, the manufacturer in his activity first of all is guided by customer interests and demands to products which have to become the high level of priority. So the paramount task for each manufacturer is assessment the customer satisfaction or in other words the level of matching products properties to customer expectations.

Practice of setting norms in standards is closely linked with consensus achievement as it is regulated in correspondent documentation. The discussion of this

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important item spread actively at present time. By the way, the importance of consensus achievement is mentioned not only in practice of standardization but in decision making process in general (Pocket guide, 2001). As the obligatory fact of decision making efficiency it is mentioned the adequate time for consensus achievement because the necessity of repeated agreements for matching positions delays the process.

Using mathematical models of quantitative assessment of the customer and manufacturer demands to product quality indices level is the perspective way for simplifying setting norms in normative documentation. Firstly, the consensus achievement point will be calculated and numerically assessed. Secondly, based on mathematical model it will be simple to compare the customer and manufacturer demands to quality index and to mark the way for their position's matching. Consequently, the developed mathematical models should be rather simple in the calculations.

A number of factors complicate the development process of mathematical models, which might be successfully applied in the practice of developing technical requirements of standards for metal products. For example, quality indices of metal products can be specified in standards in the form of different combinations of interval values. Besides, there are a number of the so-called dummy variables, which can take only two values "completed" or "not completed", or "match" or "do not match". Another factor effecting the development of the mathematical model is setting of boundary conditions and defining the assumptions. At the same time, the metal product quality indices under negotiation, which have to be agreed upon, are different in their physical and material nature, for example, geometrical dimensions, mechanical properties, chemical composition, etc. Hence, development of the mathematical model for assessing the degree of similarity between the positions of the interested parties which takes into account all peculiarities of the specified parameters is one of the goals in practice of standardization for improving the process of setting norms.

Standards of the international standards institutions, such as International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), are developed by expert groups in technical committees. The compulsory condition of approving the requirements of the international standard is to reach a consensus between all the interested parties. The wide range of participants involved in standard development activities and the large number of members of the technical committee make it difficult to reach the consensus on the technical requirements of the standard, i.e., to achieve such a level of product quality indices, which would satisfy the requirements of all the parties involved. As an example one can analyse the quantity of overdue IEC standards in 2010-2014 years. Not in vain in international standardization practice the discipline principle for all participants who take part in the process of setting norms in standards is one of the urgent ones. In another way the process of consensus achievement can drag on uncertain time.

Issues of consensus achievement during matching customer and manufacturer demands in normative and technical documentation especially in production relations, for example, contracts, agreements, technical agreements, etc, which normalise the product quality indices, are of particular importance. As a rule, these documents have to be signed before the new product is launched in the manufacturing process or when the product have to be produced with specific quality indices in general or in accordance to particular customer demands depending on the definite service application conditions. In these cases the reduction of decision making period which allows to match well all interests of customer and manufacturer is the obligatory condition for these documents approval and ensuring mutually beneficial interaction between customer and manufacturer.

Taking into consideration the abovementioned facts the application of mathematical models is very promising for solving this problem. For this purpose, for example, Markov's chain mathematical model can be used for the consensus achievement process. Based on the statistical simulation it was proved the considerable dependence of consensus achievement time on authority of experts (Kashi, 2014; Aronov, 2014, Aronov, 2015). The increase of experts quantity negatively influence on the consensus achievement period of time. At the same time the increase of experts' authority raise their disconnectedness. It shows how communications and dialog allow to achieve consensus (Aronov, 2014). Authors propose the formulae to calculate the optimal quantity of technical committee members which ensure consensus achievement in the shortest period of time saving its competence.

At present time several approaches are used in order to formalise practical activity in standardization for estimation customer satisfaction as well. In (Fudolig, 2014) authors propose to use genetic algorithm in order to estimate the level of technology innovation. But mathematical models based on genetic theory, firstly, are rather complicated for calculation, and, secondly, deal with uncertainty of the issue puzzling the model. Expectation disconfirmation theory is proposed for estimation the confirmation of initial expectation (Sahal, 1981). Authors build the relationship between unexpected outcomes and continuance intention. But this relationship is not described mathematically. S. Nicola et al (Yu, 2012) carried out the so-called Conceptual Model Decomposing Value for the Customer and showed its efficiency in a Footwear Industry. It made it possible to analyse interactions between customer and manufacturer. The proposed mathematical model is based on Fuzzy AHP method, but this method is rather complicated for calculation.

Dr. Noriaki Kano proposes to use different factors of customer satisfaction for the assessment (Zhang. 2004). Due to this theory "factors of delight" and "factors of dissatisfaction" can be estimated relative the average level of "current satisfaction". These factors can be presented like an exponential curve because such kind of curve can clearly describe the rate of increase or decrease of the parameter under investigation. "Factors of customer delight" increase gradually resulting in full extent of satisfaction by product properties. With increasing "factors of delight" the "factors of dissatisfaction" progressively tend to zero. The level which can be used for comparison of these factors is "current satisfaction". But this comparison was not evaluated mathematically that generates problems for determination of these factors.

Kano's model was used for analysis of matching m-customer satisfaction with m-customers' future purchase intentions, decisions and therewithal m-stores' future profits. Authors proved that according to Kano analysis, one dimensional and indifferent requirements for m-store design could be determined. But this investigation is based on the survey information which makes the implementation of this model rather complicated. Integrated approach to multi-criteria decision problems is proposed in (Schmitt, 2013) using quality, etc. It is the well-known fact that this kind of curve illustrates the force of function deployment and analytical network process. The author carried out the methodology which makes it possible to determine, prioritize engineering requirements based on customer needs for development of best product. For calculation it is necessary to use the hierarchy of matrix which makes calculation rather complicated.

Standardization is closely connected with changes in engineering improving the technological level of innovations (Saviotti, 1986; Blind, 2004). The results of practice in standardization can be evidently proved by quantity of inventions and patents (Yoon, 2012).

The consensus achievement can also be proved using s-curve diagram which is usually used for description of the development of different kinds of biological systems, innovation processes, in economics, engineering systems evolution perfection decreasing effectiveness (Hsu, 2016). This law describes the system development on the last stage of its life cycle. The objective necessity for creating systems using new principle of operation which means the change to the next s-shaped development curve is turned out (Nicola, 2015; Barutcu, 2015). This kind of curves is widely used for learning the limits of technological growth when «… in the time of evolution several s-shaped curves are traced» (Hsu, 2016).

The advantage of this type of curve is that for its typical form description the reliable mathematical techniques has already been carried out by now. The Belgian mathematician Pierre François Verhulst was the first who derived the formula of s-shaped curve for the description the quantity of population and named it the logistic curve. Raimond Pirl made the important contribution in the development of this approach and used it for the description of organisms' populations' variation. Biologists often call the s-shaped curve as the Pirl's curve. Henric Altshuller connected this kind of curve with quantity and quality of inventions which appear during the technical system life time (Soota, 2016). Richard Foster described manufacturing and economical processes in the companies by s-shaped curve. Boris Zlotin used this type of curve for investigation of processes and relations inside the labour collectives depending on their development stage (Hsu, 2016).

The literature review shows that although consensus is claimed to be the main condition for accepting the technical requirements of the standard, no national or international institution defines the algorithms to obtain agreement of all the parties involved into the process; no criteria have been offered to determine the level of consistency, no principles which might give shape to the process of consensus achievement have been developed. The main objectives of the present paper are to develop mathematical models, which may be used for determination the quantitative criteria of the consistency between customer and manufacturer (in other words consensus achievement) while setting norms on metal ware in different kinds of normative and technical documentation. Proposed models are based on mathematical description of s-curve diagram. It is shown that geometrical proportions of s-curve diagram can be used as the model of matching customer and manufacturer demands during setting norms of metal product. This approach is rather simple and obvious and makes it possible to calculate the moment of consensus achievement. This issue is of high practical importance because it will help to reduce time necessary for the negotiation process and speeding the process of setting norms in normative documentation.

## 2. Methodology

Standardization can be characterised by the following features of scientific knowledge (Rubin, 2013): it has the empirical basics, theoretical basics and logics, as well as the set of the achieved statements and results. Typical task of standardization consists in choosing the possible set of decisions from several of acceptable ones from which the only one, optimum, is selected for regulation in standard or any other normative documentation. Because this investigation is devoted to the metal ware standardization problems it is necessary to give concrete expression to the issues formulated above for rolled metal products as well as fasteners of industrial application (Rubin, 2015; Polyakova, 2016; Rubin, 2016; Polyakova, 2015; Klochkov, 2016).

Speaking about standardization it is necessary to distinguish the standardization in wide sense as the tendency of unification and optimisation of different units and systems interactions and standardization in the narrow sense as the activity for the setting norms in different regulatory normative and technical documentations in accordance with the demands of committees on standardization. The last area of activity is based on enormous practical experience which is perpetuated in norms and rules of national and international organizations on standardization. But in our opinion the scientific basics of this activity area are developed slightly. It happened because the subject and aims of the scientific discipline which can be used as the methodological basics for standardization are not formulated clearly (Kodzhaspirov, 2015; Kodzhaspirov, 2017; Rudskoi, 2015; Rudskoy, 2015).

Independently from the standardization subject essence any object can be characterized by the set of functions and properties which are regulated in the definite normative document. From this point of view the first aim of the standardization as the science is the development of methods for description of objects using quantitative and qualitative values. The task is actual because in practice of standardization there is no unique choice what have to be normalized: functions of the object or its properties for these functions realization. As a rule that parameters which can be measured by manufacturer during production technological process are normalized in normative or technical documentation.

In accordance with practice of metal ware standardization the normative documents regulate such quality indices, which correlate with product properties, which can be measured by definite methods and instruments, for example, mechanical properties, geometric parameters, surface characteristics etc. It is the result of long-term practice of metal ware standardization during which the transformation of customer properties changed into the classic set of properties. As a result functions which are necessary to the customer are not kept in mind during quality indices regulation. This is the main reason for origin of problems in metal ware standardization which influence the quality indices level in metal ware production.

One of the ways to solve this problem is to set the quantitative criteria which make it possible to determine the extent of consensus achievement between parties taking part in the process of setting norms for metal ware quality indices in normative and technical documentation. That is why in the frame of this investigation all parties of the standardization process are considered to be the representatives of two wide spheres: sphere of consumption and sphere of manufacturing. From this point of view quality indices can be accepted as the certain generalized expression of these spheres interests. In the following text all sphere of consumption will be denoted as customer as well as all sphere of manufacturing – manufacturer. The subject of the study will be the process of matching the positions of two sides: customer and manufacturer on the basics of customer priority. It corresponds well to the modern conception of quality management: the satisfaction of customer demands.

For developing the mathematical models of high level of accuracy it is necessary to analyze the specificity of metal ware quality indices setting. Traditionally metal ware quality indices can be normalized in following ways. Firstly, metal ware quality index can be presented as the nominal magnitude. In fact in this case the only one numerical number with dimension limit is normalized. For example, in prEN 10138-2:2000 “Prestressed reinforcement – Part 2: Wire” for normalization of wire strength parameters and geometrical dimensions the only one nominal value is indicated without any limit deviations. Secondly, metal ware quality index can be presented as the interval magnitude. In this case both interval value and nominal value with upper and lower boundaries can be used for normalization.

In the frame of this investigation the way of quality index setting has the significant importance. On the one hand, it indicates the possibility of manufacturer to produce metal ware with definite quality indices. On the other hand, both customer and manufacturer can define their own values of quality index which can be different as for the numerical nominal magnitudes as for the limit boundaries. It will inevitably influence on the consensus achievement between customer and manufacturer (Lisovenko,2016; Musabirov, 2016; Politova,2017).

The major factor which effect on the peculiarities of mathematical models development is determination of boundary limits and assumptions. Quality indices under the negotiating process are of different physical and material nature, for example, geometrical dimensions, mechanical properties, chemical composition, and, hence, they influence on customer properties at different level and in a different way. From this point of view mathematical models for the quantitative assessment of the similarity customer and manufacturer positions have to take into account peculiarities of normalized metal ware quality indices (Parshikov, 2016). Further we will define the degree of similarity between the positions of the parties by the letter *M*, which can take values within the range of. For the definition the assessment *M* firstly it is necessary to formulate the basic principle of the evaluation. This principle goes out from the modern quality management conception and consists in the priority of customer demands. The state “full satisfaction” corresponds to the value 1. If *F* is the complex of parameters which are defined by manufacturer and *U* is the complex of parameters which are defined by customer, consequently the state of consensus ($M = 1$) can be described by logic operator “→” which means that manufacturer possibilities to produce the product with definite quality indices imply customer demands.

$$\boldsymbol{F \rightarrow U} \tag{1}$$

i.e. possibilities of manufacturer totally cover the customer demands.

Situation of full consensus absence ($M = 0$) is described by the equation using logic operator “¬” which means “not”

$$\boldsymbol{F \rightarrow \neg U} \tag{2}$$

All other variants of consensus achievement will be assessed by the number from the interval.

The introduced principles can be denoted mathematically in the following way:

1) If $F \subset U$, that $M = 1$. In other words if the interval of the customer demands fully covers the interval of manufacturer demands, the assessment value is equal to 1.
2) If $F \cap U = \varnothing$, that $M = 0$. In other words the assessment value is equal to 0 at full mismatching of the intervals.
3) 3. If $F \cap U \neq \varnothing$ and $F \not\subset U$, that $M = \frac{V(F \cap U)}{V(F)}$, $0 < M < 1$.

where $M$ – the assessment of matching demands of customer and manufacturer; $V(X)$ – the interval value *X*; *X* – the variable.

Hence, the wider the interval of the intersection of the intervals which are assigned by customer and manufacture the higher the value assessment of the degree of matching the sides demands. And vice versa, the narrower the interval of the intersection of the intervals which are assigned by customer and manufacture the lower the value assessment of the degree of matching the sides demands.

In the case when customer and manufacturer demands to metal ware quality indices are denoted by nominal values the assessment of the degree of matching the sides demands can be calculated by the following equation.

$$p = \left| P_F - P_U \right| \tag{3}$$

In this case the total matching of the demands between customer and manufacturer can be denoted as following:

$$P_F = P_U \quad \text{or} \quad P_F - P_U = 0 \tag{4}$$

Mismatching can be presented in another way:

$$P_F - P_U = p_{\max} \tag{5}$$

where $p_{max}$ – maximum acceptable level of mismatching of customer and manufacturer demands.

Then the connection between the assessment and the divergence can be presented mathematically:

$$\begin{cases} \text{when } P = 0 & \text{(6a)} \\ M(P) = 0 \quad \text{when } P = p_{\max} & \text{(6b)} \end{cases}$$

It is logically to take into consideration that dependence of the assessment of the degree of similarity between the positions of customer and manufacturer from the value of the metal ware evaluated magnitude index is continuous. In other words, little deviation of the assessed metal ware index which occurs during the negotiation process between customer and manufacturer for matching their positions does not cause the intermittent changing of the assessed magnitude (Imayev, 2016)

When developing the mathematical model for assessing the similarity between the positions of the interested parties, one should take into account that in the process of developing the technical requirements of the standard, the customer and the manufacturer can set up their own values for the same parameter. Let us lay down the principles for assessing the degree of similarity between the positions of the customer and the manufacturer (Kondrat'ev, 2016). We will use the degree of overlapping of the ranges set up by the customer and the manufacturer as an assessment for the mathematical model development. In other words, the length of the overlapping interval of the quality value ranges specified by the customer and by the manufacturer will serve as basics for the assessment of the degree of similarity between the positions of the parties. This makes it possible to represent and calculate the assessment of individual quality indices, i.e. using one number, we can express the degree of difference between the positions of the parties expressed in the form of the set of integral values of parameters (Naberezhnov, 2015). So, in the case when the evaluated magnitude increases (the overlapping interval value) the assessment will also increase. In another case, the assessment will decrease when the evaluated magnitude deviates from the customer demands.

If the requirements of the manufacturer $F$ are within the range of $(a_F, b_F)$, then $V(F) = b_F - a_F$. If the requirements of the customer $U$ are within the range of $(a_U, b_U)$, then $V(U) = b_U - a_U$. If the requirements of the manufacturer are within the range of $(a_F, b_F)$, and the requirements of the customer $U$ are within the range of $(a_U, b_U)$, then depending on the overlapping degree of the values of requirements specified by the parties, we calculate the common integral value for the requirements of the customer and the manufacturer, and after that we assess the degree of similarity between the positions of the parties.

Then the assessment of the similarity of the positions of the parties will be calculated by the following relationship:

$$M = \frac{V(F \cap U)}{V(F)} \tag{7}$$

where $M$ is the assessment of similarity of the consumer and the manufacturer positions,

$V(F \cap U)$ is the length of the overlapping interval of the quality value ranges specified by the customer and by the manufacturer, $V(F)$ is the length of the range of values of the manufacturer requirements

In order to develop the mathematical tool for the calculation of the standard requirements taking into account the interval assessment of individual product quality indices specified by the customer and by the manufacturer, we will make use of the mathematical description of the S-curve given in (Rubin, 2015)

When quality index is given by interval value the increasing S-curve demonstrates the change of assessment of similarity of the consumer and the manufacturer positions in the process of coordination of requirements to the value of the parameter (Figure 1). The mathematical model can be presented by following reasons. Let's consider that $p = V(F \cap U)$. It is evident that the rate of assessment changing which is measured by the variable $\frac{dM(p)}{dp}$ near the boundary points of the first range tends to *0.*

$$\lim_{p \to 0} \frac{dM(p)}{dp} = 0 \; ; \; \lim_{p \to 1} \frac{dM(p)}{dp} = 0 \qquad (8)$$

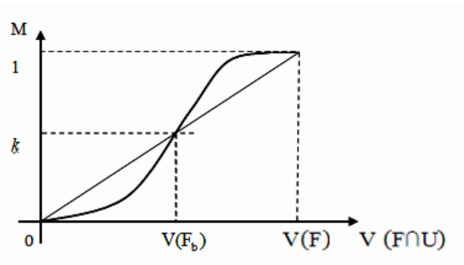


**Figure 1.** S-curve diagram as the estimation of the overlapping the parameter intervals specified by customer and manufacturer: *M* is the assessment of similarity of the consumer and the manufacturer positions; *V(F)* is some quantitative measure of the interval (in the elementary case, it is the length of the range of values of the manufacturer requirements)

It is stipulated by the following statements. At the first degree of approximation near the boundary point *0* one can estimate $\frac{dM(p)}{dp} = p$, near the boundary point *1* one can estimate the following: $\frac{dM(p)}{dp} = 1 - p$. These equations are true under the conditions that $M(0) = 0$ and $M(1) = 1$. Consequently the following equalities are true:

- near the boundary point *0* at the right
  $$M(p) = k_1 p^2 \qquad (9a)$$
- near the point *1* at the left
  $$M(p) = 1 - k_2 (p - 1)^2 \qquad (9b)$$

Hence, taking into consideration that the assessment changes continuously the following equation can be obtained:

$$k_1 p_b^2 = 1 - k_2 (p_b - 1)^2 \qquad (10)$$

where $p_b$ - the point which divides the S-curve diagram into two parts with similar rates of the assessment changing (in this case it is used as the additional point for derivation of formulae)

Using the condition that the assessment rate changes continuously the following system of equations can be obtained:

$$k_1 p_b^2 = 1 - k_2 (p_b - 1)^2 \qquad (11a)$$

$$k_1 p_b = -k_2 (p_b - 1) \qquad (11b)$$

It is evident to get formulas for $k_1$ and $k_2$ calculation:

$$k_1 = \frac{1}{p_b} \qquad (12a)$$

$$k_2 = \frac{1}{1 - p_b} \qquad (12b)$$

After substitution these equations for $k_1$ and $k_2$ into formulas (10a) and (10b), we can get the following:

$$\text{if } p_{\min} \le p \le p_b \text{, then } M(p) = \frac{p^2}{p_b}; \qquad (13a)$$

$$\text{if } p_b \le p \le 1 \text{, then } M(p) = 1 - \frac{(1 - p)^2}{(1 - p_b)} \qquad (13b)$$

Consequently:

$$M(p_b) = p_b \qquad (14)$$

In general, when $0 < k < 1$,

$$p_b = k \qquad (15)$$

$$M(p) = \frac{1}{k} \cdot p^2 \text{, when } p \le p_b \quad (16a)$$

$$M(p) = 1 - \frac{1}{1-k} \cdot (p-1)^2 \text{, } p \ge p_b \quad (16b)$$

So, in order to define the kind of relationship it is necessary to calculate the points of the first range. The level of $p_b$ and the assessment of $k = M(p_b)$ is considered to be the equation which can be used as the formula for calculation the similarity of the positions between customer and manufacturer depending on quality index of metal product. In general when 0 < k < 1.

$$M(V(F_b)) = kM(V(F)) = k \quad (17)$$

Then:

$$M(V(F \cap U)) = \frac{1}{k} \cdot \frac{(V(F \cap U))^2}{(V(F))^2},$$

when $V(F \cap U) \le V(F_b)$ (18a)

$$M(V(F \cap U)) = 1 - \frac{1}{1-k} \cdot \frac{(V(F \cap U) - V(F))^2}{(V(F))^2},$$

when $V(F \cap U) \ge V(F_b)$ (18b)

Thus the system of formulae for the calculation of the similarity of the positions between customer and manufacturer depending on quality index of metal product during the creating the normative and technical documentation in general can be presented as following:

$$M(V(F \cap U)) = \begin{cases} 0, \text{ when } V(F \cap U) = 0 \\ k, \text{ when } V(F \cap U) = V(F_b) \\ 1, \text{ when } V(F \cap U) = V(F) \\ \frac{(V(F \cap U))^2}{V(F) \cdot V(F_b)}, \text{ when } 0 \le V(F \cap U) \le V(F_b) \\ 1 - \frac{(V(F) - V(F \cap U))^2}{V(F) \cdot (V(F) - V(F_b))}, \text{ when } V(F_b) \le V(F \cap U) \le V(F) \end{cases} \quad (19)$$

When quality index is given by the nominal number with positive tolerance the following principles can be used for mathematical modelling (Polyakova, 2017). Let consider the assessment $M$ is equal to 1 at any nominal value $p_{nom}$.

$$M(p_{nom}) = 1 \quad (20)$$

At varying to the greater value the assessment is decreasing and at some maximum deviation $p^+$ the assessment value is equal to 0.

$$M(p^+) = 0 \quad (21)$$

The assessment changing rate varies when reaching to limit boundaries:

$$\lim_{p \to p_{nom}} \frac{dM(p)}{dp} = 0 \quad (22a)$$

$$\lim_{p \to p^+} \frac{dM(p)}{dp} = 0 \quad (22b)$$

Taking into consideration the continuity of assessment changing one can consider that the assessment rate changes proportionally near the boundary points. Hence near the right side of the point $p_{nom}$.

$$\frac{dM(p)}{dp} = k_1(p - p_{nom}) \quad (23)$$

and at the left side of the point $p^+$:

$$\frac{dM}{dp} = k_2(p^+ - p) \quad (24)$$

where $k_1$ and $k_2$ – numerical coefficients.

Then:

$$M(p) = k_1(p - p_{nom})^2 + 1 \qquad (25a)$$

$$M(p) = k_2\left(p^+ - p\right)^2 \qquad (25b)$$

Let denote the points $p_{nom}$ and $p^+$ as the reference points of the first order. Based on the continuity principle the following condition is true in the point $p_b$ which can be defined as the reference point of the second order.

$$k_1(p_b - p_{nom})^2 + 1 = k_2(p^+ - p_b)^2 \qquad (26)$$

Besides, on the left side of this point:

$$M'(p) = k_1(p - p_{nom}) \qquad (27a)$$

and at the right side:

$$M'(p) = k_2\left(p^+ - p\right) \qquad (27b)$$

where $M'(p)$ – the derivative of function $M(p)$, which characterise the rate of changing the dependence of the assessment the degree of matching customer and manufacturer opinions depending on their mismatching on the left and on the right sides from the reference points correspondingly

Using the additional condition of rate assessment changing continuity (the first derivative) one can achieve the system of equations

$$\begin{cases} \dfrac{k_1}{2}(p_b - p_{nom})^2 + 1 = -\dfrac{k_2}{2}(p^+ - p_b)^2, \\ k_1(p_b - p_{nom}) = k_2(p^+ - p_b) \end{cases} \qquad (28)$$

Coefficients $k_1$ and $k_2$ characterise the turn on the graph which shows the dependence of the assessment of customer and manufacturer opinions matching degree on the quality index values divergence.

It is evident from the second equation of system (28)

$$k_1 = k_2 \frac{p^+ - p_b}{p_b - p_{nom}}, \qquad (29)$$

After substitution of this expression for $k_1$ into the first equation of system (28) one can get the following:

$$k_2\left(p^+ - p_b\right)(p_b - p_{nom}) + 2 = -k_2\left(p^+ - p_b\right)^2 \qquad (30)$$

Hence $k_1$ and $k_2$ can be calculated by the following equations:

$$\left.\begin{aligned} k_1 &= \frac{-2}{(p_b - p_{nom})(p^+ - p_{nom})} \\ k_2 &= \frac{-2}{(p^+ - p_b)(p^+ - p_{nom})} \end{aligned}\right\} \qquad (31)$$

When the obtained expressions for $k_1$ and $k_2$ are substituted to (25a) and (25b), one can get the following:

if $p_{nom} \le p \le p_b$,

then $M(p) = 1 - \dfrac{(p - p_{nom})^2}{(p_b - p_{nom})(p^+ - p_{nom})}$, (32a)

if $p_b \le p \le p^+$,

then $M(p) = \dfrac{(p^+ - p)^2}{(p^+ - p_b)(p^+ - p_{nom})}$. (32b)

Then:

$$M(p_b) = \frac{p^+ - p_b}{p^+ - p_{nom}} \qquad (33)$$

In general, if

$$p_b = p_{nom} + k(p^+ - p_{nom}), \quad 0 \le k \le 1$$

Then

$$M(p_b) = M_b \qquad (34)$$

In other words, the point which connects the two parts of graph of the dependence of the assessment the degree of matching customer and manufacturer opinions depending on the difference of their appointed indices lays on the straight line between points $(p_{nom}, 1)$ and $(p^+, 0)$ (Figure 2). Let denote such type of graph as the decreasing s-curve diagram.

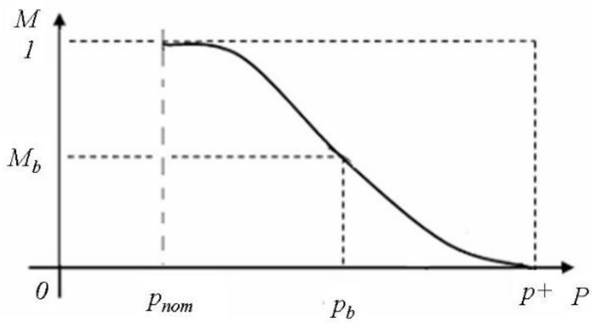


**Figure 2.** The decreasing S-curve diagram for the assessment the degree of matching customer and manufacturer opinions when the quality index is given by the nominal number with positive tolerance

Position of the point $p_b$ characterize such state when the decreasing and increasing rates of the assessment the degree of matching customer and manufacturer opinions about the index value become equal. In this case the reference point of the second order has coordinates $(p_b; 1-k)$.

## 3. Results and analysis

The first issue of application the mathematical model for the assessment the customer and manufacturer positions when quality index is defined as the interval value can be demonstrated on the example of matching properties of carbon steel wire after combined deformation processing by drawing with torsion and alternating bending with requirements in standard (Golubchik, 2014). It was shown that mechanical properties of carbon steel wire after this kind of combined deformational processing change in a wide range (Chukin, 2016; Polyakova, 2016) To implement the combined deformation processing of carbon steel wire, one can use traditional instruments applied in the manufacture of different kinds of products (wire and cable): dies and pre-forms, i.e., tools, which are commonly used at any rod-and-wire plant producing these products. Let us assume that the manufacturer interested in extending the product range and in improving the customer properties of the products has implemented the developed method of combined processing into the operating technological process of producing carbon steel wire from low-carbon steel (0.03 %C), thus providing the achievement of mechanical properties meeting the current national standard. Let us suppose that the customer of this steel wire is guided only by the requirements of this standard. In this case, it is necessary to coordinate the new capabilities of the manufacturer to produce carbon steel wire from low-carbon steel in accordance with the national standard and the position of the customer.

The results of comparison of mechanical properties of carbon steel wire after this kind of processing in accordance with the requirements specified by the national standard showed that the values of the yield strength of carbon steel wire after the combined deformation processing of drawing with torsion and alternating bending are from 520 to 590 MPa depending on the mode of processing, i.e., according to the set conditions, this is the range of values provided by the manufacturer. But at the same time according to the current national standard, the yield strength for uncoated steel wire of all diameters must be higher than 390 MPa (the position of the customer). For calculation purposes, let us assume that the upper maximum value of the yield strength is 1080 MPa. Thus, the range of values for this individual parameter, which can be provided by the manufacturer, is far narrower than the range of values specified by the customer.

The number of bendings of the wire from low-carbon steel after the combined deformation processing by drawing with torsion and alternating bending is from 13 to 15, while according to the current national standard, this amount must be no less than 9. To calculate the maximum value, let us assume that the number of bendings is 15. For this individual parameter, the range of values specified by the customer is also much wider than the range of values provided by the manufacturer (Burkovsky, 2015; Burkovsky, 2017).

The wire from low-carbon steel after the combined deformation processing by drawing with torsion and alternating bending has a significantly higher plasticity, which is why the number of twists after processing is from 47 to 57, while the amount required by the current national standard is from 14 to 20.

Figure 3 shows S-curves illustrating the possible process of matching of the values of range boundaries for the case of significant mismatch, where the value of the assessment is marked for the corresponding individual parameters.

It should be noted that according to the national standard, low-carbon steel containing 0.03 %C of carbon cannot be used for production of wire with high quality. However, the results of the analysis show that the mechanical properties of the wire from steel with such carbon content after the combined deformation processing of drawing with torsion and alternating bending meets the requirements of the standard used for other steel grades.

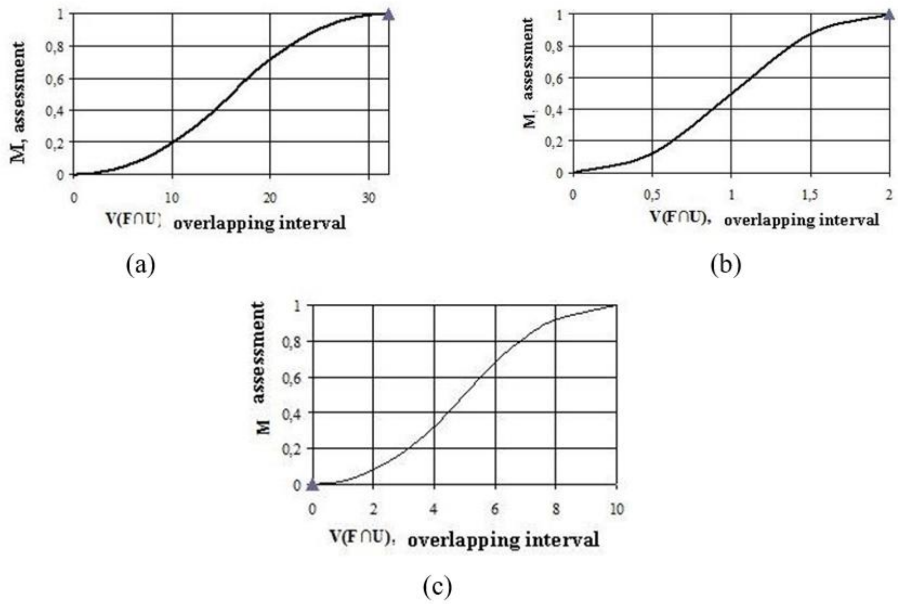


**Figure 3.** The S-curve of assessment of the similarity of the consumer and the manufacturer positions by the individual parameters of low-carbon steel wire after the combined deformation processing by drawing with torsion and alternating bending: a – yield strength; b – the number of bendings; c – the number of twists (the calculated value of the assessment is signed)

Besides, low-carbon steel wire after the combined deformation processing of drawing with torsion and alternating bending has an ultra-fine grained structure. However, the mechanical properties of metal products specified in the standards a priori assume coarse-grain structure of steel. From this point of view, the combination of strength and plastic properties characteristic for the ultra-fine grain structure goes beyond the norms specified in standards. As a result, we can consider introducing appropriate changes into the current national standard.

The second issue of application the mathematical model for the assessment the customer and manufacturer positions when the quality index is given by the nominal number with positive tolerance can be demonstrated on the example of matching properties of hexagonal head screw M16 made from carbon steel with ultrafine-graine structure with requirements in standard.

It is well known that property class for steel bolts, screws, studs and nuts is defined by their mechanical properties (ultimate strength and yield strength). Studies of peculiarities of ultrafine-graine formation in carbon steels during different kinds of plastic deformation (Valiev, 2000; Lowe, 2000; Whang, 2011) became the basics for the development the technological processes of metal ware production from steels with this kind of microstructure (Whang, 2011). As it was shown in (Koptseva, 2012), the level of hexagonal head screw M16 mechanical properties which was produced by the industrial manufacturing technology of cold forging from carbon steel with ultrafine-grained structure is the same as it is reached when alloyed steel is used (Tables 1 and 2). The mechanical properties of hexagonal head screw M16 were compared with the demands of EN ISO 898-1:2013 Mechanical Properties of Bolts, Screws and Studs (Baimova, 2017).

**Table 1.** Mechanical properties of hexagonal head screw M16 produced from carbon steel with coarse grain structure

| Fastener | Steel grade | Property class | Ultimate tensile strength $\sigma_S$, N/mm$^2$ | Yield strength $\sigma_Y$, N/mm$^2$ | KCU, MJ/m$^2$ | Hardness | Technological process |
|---|---|---|---|---|---|---|---|
| Hexagonal head screw | 0.2 %C | 4.6 | 400-500 | ------ | ------- | 110-170 HB | ------ |
| Hexagonal head screw | 0.45 %C + 1 % Mn, 0.38 %C + 1 %Cr | 8.8 | 800-1000 | 640 | 0,6 | 21-23 HRC | Cold pressure forging with quenching and tempering at high temperature |

From customer point of view it is very perspective to manufacture fasteners of industrial application from carbon steel with ultra-fine grained structure because of its typical combination of strength and plastic properties. But the level of mechanical properties which is regulated in standards a priori implies that steel has coarse grain structure. From this point of view typical for ultra-fine grained structure combination of strength and plasticity does not correlate with the level of the same properties regulated in standards. Besides, absence of information about peculiarities of steel nanostructured state in normative and technical documentation is the main factor which limits the application of such steels for metal ware manufacturing at industrial scale.

**Table 2.** Mechanical properties of hexagonal head screw M16 from carbon steel with ultrafine-grained structure

| Fastener | Steel grade | Property class | Ultimate tensile strength $\sigma_S$, N/mm$^2$ | Hexagonal head screw different parts hardness | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Thread part | | Head | | | Smooth part | |
| | | | | HRB | HRC | HB | HRB | HRC | HRB | HRC |
| M 16x55 | 0.2 %C | 6.8 | 686 | 97 | 16 | 229 | 100 | 17 | 80 | 17,5 |
| M 16x55 | 0.45 %C | 8.8 | 873 | 99 | 25 | 302 | 105 | 29 | 102 | 24 |

Lets verify the possibility of application the developed mathematical models on the example of setting norms of the hexagonal head screw M16 mechanical properties. The input data and the results of calculation of the degree of matching customer demands and manufacturer abilities for the possessing the quality index «Ultimate strength» of hexagonal head screw from carbon steel 0.2 %C in the case this steel has the ultrafine-grained structure are presented in the Table 3.

The S-shaped curve for the assessment of matching customers and manufacturer positions about the value of quality index «ultimate strength» of hexagonal head screw from carbon steel 0.2 %C with ultrafine-grained structure is plotted in Figure 4 (the calculated value of the assessment is marked).

**Table 3.** Assessment of the degree of matching customer demands and manufacturer abilities for the possessing the quality index «ultimate strength» of hexagonal head screw from steel 0.2 %C

| Assessed parameter | Value | Value of local assessment *M* |
|---|---|---|
| Manufacturer possibilities $\sigma_S$, N/mm$^2$ | 400 | 0,78 |
| Customer demands $\sigma_S$, N/mm$^2$ | 686 | |
| Mismatching, N/mm$^2$ | 286 | |

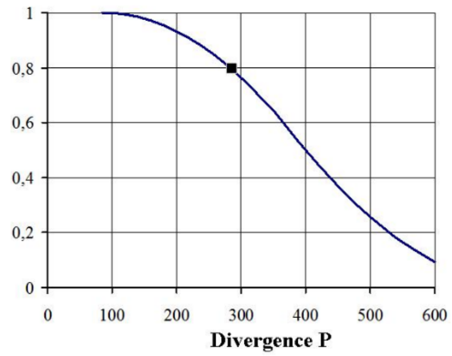


**Figure 4.** S-shaped curve for the assessment of matching customers and manufacturer positions about the value of quality index «ultimate tensile strength» of hexagonal head screw from steel 0.2 %C with ultrafine-grained structure

## 4. Conclusions

One of the basic principles for setting norms in regulatory documents is consensus achievement between customer and manufacturer. Using mathematical models of quantitative assessment of the customer and manufacturer demands to product quality indices level is the effective tool which simplifies the process of setting norms during negotiations.

Because both customer and manufacturer may establish different numerical numbers for quality index it affects the consensus achievement process. It is proposed to use S-curve diagram and its mathematical description fro the mathematical models development. It makes it possible to take into consideration the peculiarities of metal ware quality indices regulation in normative and technical documentations.

Principles for mathematical modeling the consensus achievement were formulated. They are based on the customer demands priority. When the quality index under negotiation is defined as the interval value it is necessary to use increasing S-curve diagram and its mathematical formulae for the quantitative assessment of customer and manufacturer positions. When the quality index under negotiation is defined as the nominal number with positive tolerance it is necessary to use the decreasing S-curve diagram for the quantitative assessment of customer and manufacturer positions.

The accuracy of the developed mathematical models and their applicability for different kinds of metal ware products were shown on the examples of quality indices proximity in the case of using carbon steel with ultra-fine grained structure fro the manufacturing process. The obtained results prove the perspectives and rightness of using mathematical models for quantitative assessment the consensus achievement when customer and manufacture negotiate the metal ware quality index number.

The literature analysis showed that existing mathematical models which are used in practice of standardization can not be applied for numerical estimation of customer and manufacturer positions during setting norms in regulatory documents. Consensus achievement is rather difficult process to be described by formulae. The novelty of the proposed approach is based on using S-curve diagram which can be evidently expressed mathematically. Typical for this curve sections can be applied for explanation of negotiation procedure during which consensus would be achieved.

The developed theoretical model can be used when customer and manufacturer match values of quality indices normalized by nominal value or in the form of interval. From this point of view this mathematical model can be considered to be uniform. But at the same time the difficulty consists in determining the state in the negotiation process when the rate of estimation increase is equal to the value of its rate decrease. In other words, it is rather difficult to identify the crucial moment during negotiation process between customer and manufacturer when their positions will start matching. At the same time the risk of customer is not taken into consideration in this mathematical model. This issue is of high importance in the rapidly changed market conditions. These limitations of the proposed mathematical models will become the background for further theoretical research.

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